Characterizing the performance of UV radiometers monitoring UV disinfection devices

W. Heering, H.-P. Daub

Lichttechnisches Institut (LTI), University of Karlsruhe, Karlsruhe, Germany

Abstract. According to the German DVGW regulations W294-3, radiometers that monitor the UV radiation of devices for disinfecting drinking water must have a prescribed geometry and angular response. They must match the spectral sensitivity of microorganisms and be absolutely calibrated at 254 nm. Testing facilities have been developed in the LTI to prove such features as well as linearity, aging and response to radiation out of the disinfecting spectral range. The uncertainties involved in such measurements will be discussed.

Introduction into W294-3

It is not acceptable to verify UV disinfection capacity continuously with seeding spores in drinking water in water works as it is done before during the biodosimetric challenge test. So the UV input into the reactor must be monitored on line by UV radiometers. This allows to maintain a reduction equivalent fluence REF of at least 400 J/m^2 of 253,7 nm radiation on each point inside of the reactor. As the spectral radiant power of lamps as well as the wavelength-dependent absorbance of the water vary, the monitoring detector must match the known actinic spectrum $s(\lambda)_{mic,rel}$ of disinfection. The degree of mismatch is described by the characteristic figure $f_{1,Z}$ where $s(\lambda)_{rel}$ is the relative responsivity of the radiometer to be characterized and normalized so that $s(254\,nm)_{rel} = s(254\,nm)_{mic,rel}$. $S_{\lambda,Z}(\lambda)$ is the standardized spectral distribution of the radiant power of the UV lamp Z used in the reactor.

$$f_{1,Z} = \frac{\int_{220}^{340} \left| s(\lambda)_{rel} - s(\lambda)_{mic,\,rel} \right| \cdot S_{\lambda,Z}(\lambda) \cdot d\lambda}{\int_{220}^{340} s(\lambda)_{mic,\,rel} \cdot S_{\lambda,Z} \cdot d\lambda}$$

Equation 1.

The requirements of W294-3 are $f_{1,Z} \leq 0{,}25$ for reference radiometers and $f_{1,Z} \leq 0{,}40$ for monitoring radiometers. In order to determine $f_{1,Z}$ the relative spectral responsivity of the radiometer has to be measured in the range from 220 nm to 340 nm. For a quick check of spectral mismatch of radiometers already in use, the relative response r_s and r_l to radiation, which has wavelengths shorter than 240 nm respectively longer than 300 nm, are appropriate figures of characterization. Definitions of r_s and r_l and measuring methods are given in W294-3.

Online measurements with UV radiometers at different monitoring positions and at different times of operations must be comparable. This is why radiometers for disinfection controlling have to be absolutely calibrated at the standardized wavelength of 253,7 nm. Reference radiometers are calibrated against a transfer standard radiometer which is traceable with an uncertainty of ± 5 % to a national or international standard. They are to check the monitoring radiometers of UV devices and especially to calibrate them. As the microbicidal irradiances on the monitoring radiometers of the reactor are up to four magnitudes higher than the irradiance level at which calibration occurs, linearity has to be tested additionally, i.e. up to 10 kW/m2 when medium pressure mercury lamps are installed.

For comparable measurements, UV radiometers for monitoring as well as those for validation must have identical angular response and entrance dimensions. In the Austrian Standard ONORM M5873-1 (2001) an acceptance (full) angel of 160° is established, in the German Standard DVGW W294 (1997) it was fixed to 40°. In each case an irradiance signal is aimed which changes nearly to the same degree as flow changes at the same REF. In the water reactor the measuring radiometer head with its entrance window made of quartz glass is separated by an 1 mm air gap and a 5 mm thick quartz window in the wall of the reactor from the water. So, because of additional refraction an incident angle on the air side of 40° respectively 160° which is really to be tested corresponds to an incident angle on the water side of only 28,8° respectively 91,4°. Furthermore a cosine response is expected within the angular range of the detector; $f_2 \leq 0{,}03$ for the 40° radiometer, $f_2 \leq 0{,}20$ for the 160° detector. Both, acceptance angle as well as cosine response, are given if the angular response is within the lower and upper curves shown for the 40° sensor in Figure 1.

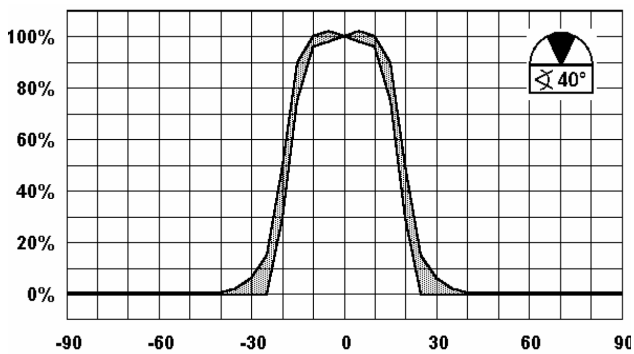

Figure 1 Angular tolerances of the 40° detector head

Testing facilities

Measuring arrangements have been developed and verified in order to determine the characteristic features of UV radiometers according to the W294-3 regulations. The key quantity used for characterization is the spectral responsivity of the UV radiometer under test. Its spectral distribution is measured in the whole air UV by comparing its photosignal produced by monochromatic irradiation at different wavelengths with that from a standard detector at the same position. Quasi-monochromatic radiation is obtained by filtering the focused radiation from a xenon arc lamp XBO 450W/4 by a BENTHAM monochromator M300 HRA/2. The spectral half-width set at 2.0 nm is a compromise between sufficient irradiance on the detector and spectral resolution. The reference detector is a silicon photodiode HAMAMATSU S1227-1010BQ within a blackened and temperature-controlled aluminum housing and covered with an aperture stop of 7 mm diameter.

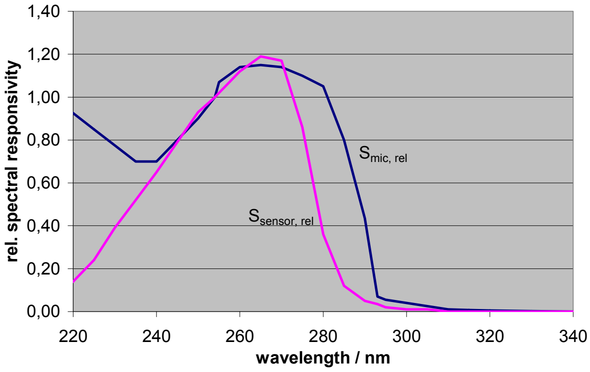

Figure 2 Measured rel. spectral radiometer responsivities $s_{sensor,rel}$ and spectrum $s_{mic,rel}$ of microbicidal action

A typical monitoring UV radiometer with responsivity curve as shown in Figure 2 fulfills $f_{1,Z} < 0.40$ if Z is for a mercury medium pressure lamp but it has too high short wave responses r_s.

Absolute spectral responsivities are obtained by calibration at 254 nm where the relative responsivity is normalized to one. The standard detector for comparison is of the same type as used for the measurement of relative spectral responsivities. At the PTB, its absolute differential spectral responsivity (DSR) has been determined for different bias currents in the range from 210 nm to 420 nm. Here, the monochromatic source is a capillary mercury low pressure lamp within a ellipsoidal reflector. The reflector opening is imaged by a Suprasil lens via an interference reflection filter with center wavelength of 254 nm and HWHM = 40 nm onto the window of the detector so that its entrance is just fully irradiated. The UV lamp is supplied by an electronic control gear and regulated by means of a monitoring SiC diode to a constant output. The extraordinary properties of this UV unit are to give a monochromatic irradiance of 6.63 W/m^2 and a uniformity of irradiance so that the irradiance within a diameter of 13 mm is only by a factor of 0.95 smaller than that within a diameter of 7 mm. Always the plane of the diffuser of the radiometer head has to be taken as the measuring plane. So take into consideration that the diffuser plane of the DVGW sensor is 20 mm behind the corresponding plane of the ONORM sensor.

Linearity tests are based on the condition that the reference detector, here a silicon photodiode HAMAMATSU S1227-1010BQ, used to compare photosignals at the same irradiance level is linear. This is true up to a short circuit current of about 5 mA corresponding to a reduction equivalent irradiance of about 1000 W/m^2. The lamp used to produce so high irradiances is a stabilized CERMAX xenon short arc lamp PE300BUVM with parabolic reflector. As the silicon photodiode is strongly responsive in the VIS and NIR where the UV radiometer is blind, the settings of different irradiance levels should be done by non-selective attenuation. We have realized this by means of metal meshes of different density.

In order to measure the angular response, the UV detector head under test is rotated around a middle axis through the outer surface of the entrance window. The CERMAX lamp described before produces behind a circular aperture stop a beam with half aperture angle of 2°. All UV radiometers which have been tested up to now according to W294-3 are within the prescribed limits of angular response and have the requested cosine response.

Other characteristic features as temperature dependence and aging of responsivity have to be proved. The respective testing facilities and measurements will be presented in the complete paper on radiometers for disinfection devices.

References

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